CHAPTER 850
PHYSICAL STANDARDS

Topic 851 - General

Index 851.1 - Introduction

This section deals with the selection of drainage facility material size and type(s).

851.2 Selection of Material and Type

The choice of drainage facility material size and type is based on the following factors:

(1) *Physical and Structural Factors.* Of the many physical and structural considerations, some of the most important are:

(a) Durability.

(b) Headroom.

(c) Earth Loads.

(d) Bedding Conditions.

(e) Conduit Rigidity.

(f) Impact.

(g) Watertightness.

(2) *Hydraulic Factors.* Hydraulic considerations involve:

(a) Design Discharge.

(b) Shape, slope and cross sectional area of channel.

(c) Velocity of approach.

(d) Outlet velocity.

(e) Total available head.

(f) Bedload.

(g) Inlet and outlet conditions.

(h) Slope.

(i) Smoothness of conduit.

(j) Length.

Suggested values for Manning's Roughness coefficient (n) for design purposes are given in Table 851.2 for each type of conduit. See Index 864.3 for use of Manning's formula.

(3) *Maintenance and Construction Factors.*

(a) Local experience.

(b) Accessibility of site.

(c) Construction conditions.

(4) *Economy.* Comparative cost should be weighed on a long-term basis considering the factors given under Index 801.5.

Topic 852 - Design Service Life

852.1 Basic Concepts

The prediction of design service life of drainage facilities is difficult because of the large number of variables, continuing changes in materials, wide range of environments, and use of various protective coatings. The design service life of a drainage facility is defined as the expected maintenance free service life of each installation.

For corrugated metal pipe culverts (CMP), maintenance free service life, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of perforation at any location on the culvert (See Figure 854.3B).

For reinforced concrete pipe culverts (RCP), maintenance free service life, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of exposed reinforcement at any point on the culvert.

All types of culverts are subject to deterioration from corrosion, abrasion, or both. Corrosion may result from active elements in the soil, water and/or atmosphere. Mechanical wear depends upon the frequency, duration and velocity of flow, and the amount and character of bedload.

To assure that the maintenance free service life is achieved, alternative metal pipe may require added thickness and/or protective coatings. Concrete pipe may require extra thickness of concrete cover over the steel reinforcement, high density concrete, and/or protective coatings. Means for estimating the maintenance free service life of pipe, and techniques for extending the useful life of pipe materials are discussed in more detail in Topic 854.

Table 851.2

Manning N-Value for Alternative Pipe Materials[(1)]

Type of Conduit		Recommended Design Value	N-Value Range
Corrugated Metal Pipe [(2)]			
(Annular and Helical) [(3)]			
68 mm x 13 mm	corrugation	0.025	0.022 - 0.027
76 mm x 25 mm	"	0.028	0.027 - 0.028
125 mm x 25 mm	"	0.026	0.025 - 0.026
152 mm x 51 mm	"	0.035	0.033 - 0.035
229 mm x 64 mm	"	0.035	0.033 - 0.037
Concrete Pipe			
Pre-cast		0.012	0.011 - 0.017
Cast-in-place		0.013	0.012 - 0.017
Concrete Box		0.013	0.012 - 0.018
Plastic Pipe			
Smooth Interior		0.012	0.010 - 0.013
Corrugated Interior		0.022	0.020 - 0.025
Spiral Rib Metal Pipe			
19 mm (W) x 25 mm (D) @ 292 mm o/c		0.013	0.011 - 0.015
19 mm (W) x 19 mm (D) @ 191 mm o/c		0.013	0.012 - 0.015
Steel Pipe, Ungalvanized		0.015	--
Cast Iron Pipe		0.015	--
Clay Sewer Pipe		0.013	--

(1) Tabulated n-values apply to circular pipes flowing full. For noncircular or partially full conduits the tabulated values may be modified as shown in Appendix B of HDS No. 5, Hydraulic Design of Highway Culverts.

(2) For lined corrugated metal pipe, a composite roughness coefficient may be computed using the procedures outlined in the HDS No. 5, Hydraulic Design of Highway Culverts.

(3) Lower n-values may be possible for helical pipe under specific flow conditions (refer to FHWA's publication Hydraulic Flow Resistance Factors for Corrugated Metal Conduits), but in general, it is recommended that the tabulated n-value be used for both annular and helical corrugated pipes.

The design service life for drainage facilities for all projects should be as follows:

(1) *Culverts, Drainage Systems, and Side Drains.*

(a) Roadbed widths greater than 8.4 m - 50 years.

(b) Greater than 3 m of cover - 50 years.

(c) Roadbed widths 8.4 m or less and with less than 3 m of cover - 25 years.

(d) Installations under interim alignment - 25 years.

(2) *Overside Drains.*

(a) Buried more than one meter - 50 years.

(b) All other conditions, such as on the surface of fill slopes - 25 years.

(3) *Subsurface Drains.*

(a) Underdrains within roadbed - 50 years.

(b) Underdrains outside of roadbed - 25 years.

(c) Stabilization trench drains - 50 years.

In case of conflict in the design service life requirements between the above controls, the highest design service life is required except for those cases of interim alignment with more than 3 m of cover. For temporary construction, a lesser design service life than that shown above is acceptable.

Where the above indicates a minimum design service life of 25 years, 50 years may be used. For example an anticipated change in traffic conditions or when the highway is considered to be on permanent alignment may warrant the higher design service life.

Topic 853 - Alternate Materials

853.1 Basic Policy

When two or more materials meet the design service life, and structural and hydraulic requirements, the plans and specifications must provide for alternative pipes, pipe arches, overside drains, and underdrains to allow for optional selection by the contractor.

(1) *Allowable Alternatives.* A table of allowable alternative materials for culverts, drainage systems, overside drains, and subsurface drains is included as Table 853.1A. This table also identifies the various joint types described in Index 853.1(2) that should be used for the different types of installations.

(2) *Joint Requirements.* The Standard Specifications set forth general performance requirements for transverse field joints in all types of culvert and drainage pipe used for highway construction, such as corrugated metal pipe, and reinforced and plain concrete pipe.

Table 853.1A indicates the alternative types of joints that are available for different arch and pipe installations. The two joint types specified for culvert and drainage systems are identified as "standard" and "positive".

The type of joint required for a particular installation is to be designated on the culvert list.

(a) Standard Joints. The "standard" joint is usually for pipes or arches not subject to large soil movement or disjointing forces. These "standard" joints are satisfactory for ordinarily installations, where tongue and groove or simple slip type joints are typically used. The "standard" joint type is generally adequate for underdrains.

(b) Positive Joints. "Positive" joints are for more adverse conditions such as the need to withstand soil movements or resist disjointing forces. Examples of these conditions are steep slopes, sharp curves, and poor foundation conditions. (See Index 829.2 for additional discussion.) "Positive" joints should always be designated on the culvert list for siphon installations.

(c) Downdrain Joints. Pipe "downdrain" joints are designed to withstand high velocity flows, and to prevent leaking and disjointing that could cause failure.

(d) Joint Properties. A description of the specified joint properties tabulated in Table 853.1B is as follows:

- Shear Strength. The shear strength required of the joint is expressed as

Table 853.1A

Allowable Alternate Materials

Type of Installation	Service Life (yrs)[1]	Allowable Alternatives	Joint Type Standard	Joint Type Positive	Joint Type Downdrain
Culverts & Drainage Systems	50	ASRP, CAP, CASP, CIPCP, CSP, NRCP, SAPP, SSPP, SSRP, RCP, RCB, PPC	X	X	--
Overside Drains	50	CAP, CASP, CSP	--	--	X
Underdrains	50	PAP, PSP, PPET, PPVCP	X	--	--
Arches (Culverts & Drainage Systems)	50	CAPA, CSPA, RCA, SAPPA, SSPPA, SSPA	X	X	--

LEGEND

ASRP - Aluminum Spiral Rib Pipe
CAP - Corrugated Aluminum Pipe
CAPA - Corrugated Aluminum Pipe Arch
CASP - Corrugated Aluminized Steel Pipe, Type 2
CIPCP - Cast-in-Place Concrete Pipe
CSP - Corrugated Steel Pipe
CSPA - Corrugated Steel Pipe Arch
NRCP - Non-Reinforced Concrete Pipe
PAP - Perforated Aluminum Pipe
PPC - Plastic Pipe Culvert
PPET - Perforated Polyethylene Tubing
PPVCP - Perforated Polyvinyl Chloride Pipe
PSP - Perforated Steel Pipe
RCA - Reinforced Concrete Arch
RCB - Reinforced Concrete Box
RCP - Reinforced Concrete Pipe
SAPP - Structural Aluminum Plate Pipe
SAPPA - Structural Aluminum Plate Pipe Arch
SSPA - Structural Steel Plate Arch
SSPP - Structural Steel Plate Pipe
SSPPA - Structural Steel Plate Pipe Arch
SSRP - Steel Spiral Rib Pipe
X - Permissible Joint Type for the Type of installation Indicated

NOTE:
1. The design service life indicated for the various types of installations listed in the table may be reduced to 25 years in certain situations. Refer to Index 852.1 for a discussion of service life requirements.

Table 853.1B

Culvert Joint Property Requirements

Joint Property	Standard	Positive	Downdrain
Shear Property	2%	5%	5%
Moment Strength	0%	15%	15%
Tensile Strength			
(150 mm - 1050 mm diam.)	0	0	22,500 N
(1200 mm - 2100 mm diam.)	0	0	45,000 N
Joint Overlap			
Integral - (300 mm - 825 mm diam.)	13 mm Min.	19 mm Min.	Not Required
(400 mm - 2700 mm diam.)	19 mm Min.	25 mm Min.	Not Required
Sleeve-min. width	265 mm	265 mm	265 mm

NOTE: Refer to Standard Specifications, Section 61, Culvert and Drainage Pipe Joints.

a percentage of the calculated shear strength of the pipe at a transverse section remote from the joint. All joints, including any connections must be capable of transferring the required shear across the joint.

- Moment Strength. The moment strength required of the joint is expressed as a percent of the calculated moment capacity of the pipe on a transverse section remote from the joint.

- Tensile Strength. The tensile strength is that which resist the longitudinal force which tends to separate (disjoint) adjacent pipe sections.

- Joint Overlap.

  Integral Preformed Joint. The Joint overlap is the amount of protection of one culvert barrel into the adjacent culvert barrel by the amount specified for the size of pipe designated.

  Any part of an installed joint that has less than 6 mm overlap will be considered disjointed. Whenever the plans require that the culvert be constructed on a curve, specially manufactured sections of culvert will be required if the design joint cannot meet the minimum 6 mm overlap requirement after the culvert section is placed on the specified curve.

  Sleeve Joints. The joint overlap is the minimum sleeve width required to engage both the culvert barrels which are abutted to each other.

(3) *Joint Performance.* The ability of a pipe joint to prevent the passage of either soil particles or water defines its soiltightness or watertightness. These terms are relative and do not mean that a joint will be able to completely stop the movement of soil or water under all conditions. Any pipe joint that allows significant soil migration (piping) will ultimately cause damage to the embankment, the roadway, or the pipe itself. Therefore, site conditions, such as soil particle size, presence of groundwater, potential for pressure flow, etc., must be evaluated to determine the appropriate joint requirement. Other than solvent or fusion welded joints, almost all joints can exhibit some amount of leakage. Joint performance is typically defined by maximum allowable opening size in the joint itself or by the ability to pass a standardized pressure test. The following criteria should be used, with the allowable joint type(s) indicated on the project plans:

- Normal Joint. Many pipe joint systems are not defined as either soiltight or watertight. However, for the majority of applications, such as culverts or storm drains placed in well graded backfill and surrounding soils containing a minimum of fines; no potential for groundwater contact; limited internal pressure, hydraulic grade line below the pavement grade, etc., this type of joint is acceptable. All currently accepted joint types will meet or exceed "Normal Joint" requirements. The following non-gasketed joint types should not be used beyond the "Normal Joint" criteria range:

<u>CMP</u>	-Annular -Hat -Helical -Hugger -2-piece Integral Flange -Universal
<u>PLASTIC</u>	-Split Coupler -Bell/Spigot

- Soiltight Joint. This category includes those joints which would provide an enhanced level of security against leakage and soil migration over the normal joint. One definition of a soiltight joint is contained in Section 26.4.2.4(e) of the AASHTO Standard Specifications for Highway Bridges. In part, this specification requires that if the size of the opening through which soil might migrate exceeds 3 mm, the length of the channel (length of path along which the soil particle must travel, i.e., the coupling length) must exceed 4 times the size of the opening. Alternatively, AASHTO allows the joint to pass a hydrostatic test (subjected to approx. 1.4 m of head) without leaking to be considered soiltight. Typical pipe joints that can meet this criteria are:

RCP and NRCP	-Flared Bell -Flush Bell -Steel Joint-Flush Bell -Flared Bell (Type R-3) -Double Gasket -Tounge and Groove* -Self Centering T & G*
CMP	-Annular w/gasket -Hat w/gasket -Helical w/gasket -Hugger w/gasket -2-piece Int. Fl. w/gasket -Universal w/gasket
PLASTIC	-Split Coupler w/gasket (premium) -Bell/Spigot w/gasket

* Where substantial differential settlement is anticipated, would only meet Normal Joint criteria.

Where soil migration is of concern, but leakage rate is not, a soiltight joint can be achieved in most situations by external wrapping of the joint area with filter fabric (see Index 831.4). Joints listed under both the normal joint and soiltight joint categories, with a filter fabric wrap, would be suitable in these conditions and would not require a gasket or sealant. In many cases, fabric wrapping can be less expensive than a rubber gasket or other joint sealant. Coordination with the District Materials Unit is advised to verify that standard filter fabric described in Standard Specification Section 88-1.03 is of sufficient strength to withstand forces applied during construction (heavier fabric may be specified) and that fabric will effectively screen fine soil particles from passage.

- Watertight Joint. Watertight joints are specified when the potential for soil erosion or infiltration/exfiltration must be restricted, such as for downdrains, culverts in groundwater zones, etc. Watertight joint requirements are typically met by the use of rubber gasket materials as indicated in the Standard Specifications. The watertight certification test described in Standard Specification Section 61 requires that no leakage occur when a joint is tested for a period of 10 minutes while subjected to a head of 3 m over the crown of the pipe. This is a test that is typically performed in a laboratory under optimal conditions not typical of those found in the field. Where an assurance of watertightness is needed, a field test should be specified. Designers should be aware that field tests can be relatively expensive, and should only be required if such assurance is critical. A field leakage rate in the range of 70-100 1/ mm of nominal diameter / km of pipe length / day, with a hydrostatic head of 2 m above the crown of the pipe, is not unusual for joints that pass the watertight certification test, and is sufficiently watertight for well graded, quality backfill conditions. Where conditions are more sensitive, a lower rate should be specified. Rates below 5 - 10 1/mm / km / day are difficult to achieve and would rarely be necessary. For example, sanitary sewers are rarely required to have leakage rates below 20 1 / mm / km / day, even though they have stringent health and environmental restrictions. Field hydrostatic tests are typically conducted over a period of 24 hours or more to establish a valid leakage rate. Desigers should also be aware that non-circular pipe shapes (CMP pipe arches, RCP oval shapes, etc.) should not be considered watertight even with the use of rubber gaskets or other sealants due to the lack of uniform compression around the periphery of the joint. Additionally, watertight joints specified for pressure pipe or siphon applications must meet the requirements indicated in Standard Specification Sections 65 and 66. Pipe joints that meet Standard Specification Section 61 water-tightness performance criteria are:

RCP and NRCP	– Flared Bell – Flush Bell – Steel Joint-Flush Bell – Flared Bell (Type R-3) – Double Gasket
CMP	– Hugger Bands (H-267, 305) w/gasket and double bolt bar – Annular Band w/gasket – Two Piece Integral Flange w/sleeve-type gasket*
PLASTIC	– Bell/Spigot w/gasket

*Acceptable as a watertight pipe only in downdrain applications and in 150, 200 and 250 mm diameters. Factory applied sleeve-type gaskets are to be used instead of O-ring or other sealants.

Table 853.1C provides information to help the designer select the proper joint under most conditions.

(4) *Design Service Life.* Each pipe type selected as an alternative must have the appropriate protection as outlined in Topic 854 to assure that it will meet the design service life requirements specified in Topic 852. The maximum height of cover must be in accordance with the tables included in Topic 854.

(5) *Selection of a Specific Material Type.* In the cases listed below, the selection of a specific culvert material must be supported by a complete analysis based on the foregoing factors. All pertinent documentation should be placed on file in the District.

- Where satisfactory performance for a life expectancy of 25 or 50 years, as defined under design service life, cannot be obtained with certain materials by reason of highly corrosive conditions, severe abrasive conditions, or critical structural and construction requirements.
- For individual drainage systems such as roadway drainage systems or culverts which operate under hydrostatic pressure or culverts governed by hydraulic considerations and which would require separate design for each culvert type.
- When alterations or extensions of existing systems are required, the culvert type may be selected to match the type used in the existing system.

853.2 Alternative Selection

Each alternative material selected for a drainage facility must provide the required design service life based on physical and structural factors, be of adequate size to satisfy the hydraulic design, and require the minimum of maintenance and construction cost for each site condition.

853.3 Alternative Pipe Culvert List

Table 853.3 shows a method of designating the type of material, size, class, thickness, protection, etc., for each type of allowable material. A similar table should be included in the plans adjacent to the drainage list when alternative materials are allowed. Because of the difference in roughness coefficients between various materials, it may be necessary to specify a different size for each allowable material at any one location. In this event, it is recommended that the material with the smallest dimension be listed as the alternative size. Refer to Drafting and Plans Manual for standard format to be used.

Table 853.1C

Joint Selection Criteria

JOINT TYPE / SITE CONDITIONS	"NORMAL" JOINT	"SOILTIGHT" JOINT	"WATERTIGHT" JOINT
SOIL FACTORS			
Limited potential for soil migration (e.g., gravel, medium to coarse sands, cohesive soil)	X	X	X
Moderate potential for soil migration (e.g., fine sands, silts)	X(1)	X	X
High potential for soil migration (e.g., very fine sands, silts of limited cohesion)		X(1)	X(1)
INFILTRATION / EXFILTRATION			
No concern over either infiltration or exfiltration.	X	X	X
Infiltration or exfiltration not permitted (e.g., potential to contaminate groundwater, contaminated plume could infiltrate)			X(2)
HYDROSTATIC POTENTIAL			
Installation will rarely flow full. No contact with groundwater.	X	X	X
Installation will occasionally flow full. Internal head no more than 3 m over crown. No potential groundwater contact.		X	X
Installation may or may not flow full. Internal head no more than 3 m over crown. May contact groundwater.			X
Possible hydrostatic head (internal or external) greater than 3 m, but less than 7.5 m(3).			X(2)

"X" indicates that joint type is acceptable in this application. The designer should specify the most cost-effective option.
[1] Designer should specify filter fabric wrap at joint. See Index 831.4.
[2] Designer should consider specifying field watertightness test.
[3] Pipe subjected to hydrostatic heads greater than 7.5 m should have joints designed specifically for pressure applications.

Table 853.3

Example Listing of Alternative Pipe Culverts and Pipe Arch Culverts

ALLOWABLE PIPE MATERIAL AND PROTECTION

	RCP(1)	CSP				CAP				RCB		PLASTIC	
Designation	Size (mm)	Size (mm)	Thick. (mm)	Bitum. Coating	Bitum. Coat Pav'd Inv.	Size (mm)	Thick. (mm)	Bitum. Coating	Bitum. Coat Pav'd In.	Span x Ht. (m)	Max. Cover (m)	Corrug. Inter.[3] (mm)	Smooth Inter.[3,4] (mm)
450 mm Alt. Pipe (Type A)	450	450	1.63	No	No	450	1.52	No	No	--	--	450	450
450 mm Alt. Pipe (Type B)	450	600	1.63	Yes	No	600	1.52	No	No	--	--	600	450
600 mm Alt. Pipe (Type A)	600	600	1.63	No	No	600	1.52	No	No	--	--	600	600
600 mm Alt. Pipe (Type B)	600	750	2.01	Yes	Yes	--	--	--	--	--	--	--	600
600 mm Alt. Pipe (Type C)	--	600	2.01	No	No	600	3.43	No	No	--	--	--	--
900 mm Alt. Pipe (Type A)	900	1050	2.77	Yes	Yes	1050	3.43	No	No	--	--	--	--
900 mm Alt. Pipe (Type B)	900	900	2.01	Yes	No	900	2.67	No	No	--	--	--	900
1200 mm Alt. Pipe (Type A)	1200	1200	2.01	No	No	1200	2.67	No	No	--	--	--	1200
1200 mm Alt. Pipe (Type B)	1200	1350	2.77	Yes	Yes	1350	3.43	No	No	--	--	--	--
1225 mm x 825 mm Alt. Pipe Arch	--	1225 x 825	2.01	Yes	No	1225 x 825	2.67	No	No	--	--	--	--
1500 mm Alt. Pipe	1500	1650	2.01	No	No	1650	2.67	No	No	--	--	--	--
1950 mm Alt. Pipe (Type A)	1950	125 x 25 1950	2.77	No	No	1950	3.43	No	No	--	--	--	--
1950 mm Alt. Pipe (Type B)	1950	75 x 25 1950	2.01	No	No	--	--	--	--	1.8 x 1.8	6	--	--

NOTES:

(1) See Standard Plan A62D for RCP strength classification and method of backfill.

(2) Coupler Type must be shown on Culvert List. (S=Standard, P=Positive, D=Downdrain)

(3) See Standard Specifications Section 64-1.03 for available and allowable plastic pipe sizes.

(4) Smooth interior plastic pipe may be either Type S or Type D HDPE; Ribbed HDPE; or Ribbed PVC pipe at the contractors option. See Section 64 of the Standard Specifications.

There may be situations where there is a different set of alternatives for the same nominal size of alternative drainage facilities. In this case the different sets of the same nominal size should be further identified by different types, for example, 450 mm alternative pipe culvert (Type A), 450 mm alternative pipe culvert (Type B), etc. No attempt to correlate type designation between projects is necessary. The first alternative combination for each culvert size on each project should be designated as Type A, second as Type B, etc.

Since the available nominal sizes for pipe arches vary slightly between pipe arch materials, it is recommended that the listed alternative pipe arch sizes conform to those sizes shown for corrugated steel pipe arches shown on Table 854.3E. The designer should verify the availability of reinforced concrete pipe arches. If reinforced concrete pipe arches are not available, oval shaped reinforced concrete pipe of a size necessary to meet the hydraulic requirements may be used as an alternative.

Topic 854 - Kinds of Pipe Culverts

854.1 Reinforced Concrete Pipe

(1) *Durability.* The durability of reinforced concrete pipe can be affected by acids, chlorides and sulfate concentrations in the soil and water. Table 854.1A indicates the limitation on the use of concrete by acidity of soil and water. Table 854.1B is a guide for designating type of cement and cement factor to use for various ranges of sulfate concentrations in soil and water. California Test 532 is useful for anticipating the effect chlorides in the environment have on the time to corrosion of the embedded steel. In addition to the protective measures noted above, the following measures increase the durability of reinforced concrete culverts.

(a) Cover Over Reinforcing Steel. Additional cover over the reinforcing steel should be specified where abrasion is likely to be so severe as to appreciably shorten the design service life of a concrete culvert. This extra thickness is also warranted under exposure to corrosive envionments. Extra cover over the reinforcing steel does not necessarily require extra wall thickness, as it may be possible to provide the additional cover and still obtain the specified D-load with standard wall thicknesses. Refer to Topic 8.22 of the Bridge Design Specifications Manual for minimum concrete cover for reinforcing steel.

(b) Density. High density concrete pipe as achieved by spinning or other process should be considered under exposure to salt air, salt water, or other highly corrosive locations.

(2) *Strength Requirements.*

(a) Design Standards. The strength of reinforced concrete pipe is determined by the load to produce a 0.3 mm crack under the 3-edge bearing test called for in AASHTO Designations M 170M, M 207M, and M 206M for circular reinforced pipe, oval shaped reinforced pipe, and reinforced concrete pipe arches, respectively.

(b) Height of Fill. Table 854.1C gives the maximum height of overfill for reinforced concrete pipe, up to and including 2700 mm diameters (or reinforced oval pipe and reinforced concrete pipe arch with equivalent cross-sectional area), using the backfill method specified in Standard Specification Section 19-3.06, Structure Backfill, which is referred to as "Method A Backfill" in Table 854.1C. Any plan to utilize any other culvert backfill method that varies from the specified Method A backfill must be submitted to the Division of Structures for an evaluation of the structural adequacy of the proposed installation. Table 854.1C tabulates the same data given in the Standard Plan A62-D, E and F. It is included here to give the designer an understanding of the basis for the tables shown in the Standard Plan referred to above.

The designer should be aware of the premises on which the table is computed as well as its limitations. Table 854.1C presupposes:

- That the bedding and backfill satisfy the terms of the Standard Specifications, the conditions of cover and pipe size required by the plans, and take into account the essentials of Index 829.2.

- That a small amount of settlement will occur under the culvert equal in magnitude to that of the adjoining material outside the trench.

- Subexcavation and backfill as required by the Standard Specifications where unyielding foundation material is encountered.

(c) Special Designs.

- If the height of overfill exceeds the tabular values a special design is required; see Index 829.2.

- Where severe abrasion or wear from high velocity is anticipated, at least 50 mm of cover over the reinforcing steel must be specified by special provision. Specifying thick wall pipe will not assure 50 mm of cover over the steel.

- In corrosive environments, consideration must be given to the requirements of Index 854.1(1).

(3) Shapes. Reinforced concrete culverts are available in circular and oval shapes. Reinforced concrete pipe arch (RCPA) shapes have been discontinued by West Coast manufacturers.

In general, the circular shaped is the most economical for the same cross-sectional area. Oval shapes are appropriate for areas with limited head or overfill or where these shapes are more appropriate for site conditions. A convenient reference to commercially available products and shapes is the AASHTO publication, "A Guide to Standardized Highway Drainage Products".

(4) Invert Protection. Invert protection should be considered for culverts exposed to excessive wear from abrasive flows. Continued maintenance can be expected if the culvert is not adequately designed for severe abrasion. When severe abrasion is anticipated, special designs should be investigated and considered. Higher initial costs can probably be justified on the basis it would be more economical than later repair or replacement costs. Typical invert protection includes increased wall thickness, invert paving with portland cement concrete with wire mesh reinforcement, and invert lining with metal plate, channel iron, or rails. Invert linings should cover the lower fourth of the periphery of circular pipes, and the lower third of pipe arches.

(5) Non-Reinforced Concrete Pipe Option. Non-reinforced concrete pipe may be substituted at the contractors option for reinforced concrete pipe for all sizes 900 mm in diameter and smaller as long as it conforms to Section 65 of the Standard Specifications. Non-Reinforced concrete pipe is not affected by chlorides or stray currents and may be used in lieu of RCP in these environments without coating or the need to provide extra cover over reinforcement.

(6) Direct Design Method - RCP. (Contact Division of Structures)

854.2 Cast-in-Place Non-reinforced Concrete Pipe

(1) *Design Criteria.*

(a) Use of cast-in-place concrete pipe should not be considered when an unstable trench condition occurs; for example, it should not be installed under the following conditions.

- Sandy and cohesionless soil.

- Shallow location in expansive soil where the volume change would crack pipe.

Table 854.1A

Limitation on Use of Concrete Pipe[1] by Acidity of Soil and Water

Acidity pH	Remarks
5.5 or less[2]	Use reinforced concrete pipe with extra cover or a protective coating[2]

NOTE:

(1) Although indicated specifically for concrete pipe, limitations shown are valid for all concrete structures.

(2) If soil and/or water have a pH of 5.5 or less, cast-in-place pipe should not be used.

(3) Consult METS Concrete Section.

Table 854.1B

Guide for Sulfate Resisting Concrete Pipe and Other Concrete Drainage Structures[1, 2]

Water-Soluble Sulfate in Soil Sample[3] (Percent)	Sulfate in Water Sample[3] (Parts per Million)	Type of Cement	Cement Content
0-0.20	0-2000	II Modified	Minimum required by Specifications
0.20-0.50	2000-5000	V II Modified	Minimum required by Specifications 400 kg/m^3
0.50-1.50	5000-15000	V II Modified	Minimum required by Specifications 400 kg/m^3, w/c of 0.40 or less, AE[4]
Over 1.50	Over 15000	V	400 kg/m^3, w/c of 0.40 or less, AE[4]

NOTE:

(1) Type of cement and cement content requirements as listed are applicable to all concrete structures for the given sulphate concentrations.

(2) Recommended measures for type and amount of cement based on analysis of sulfate content in soil and water.

(3) Reported as SO_4.

(4) Air-Entrainment, air content 5% +/- 1%.

Table 854.1C

Strength and Uses of Reinforced Concrete Pipe for Diameters from 300 mm to 2700 mm

Class[1] of Pipe	Cracking[1] D-Load (N/m/mm)	Ultimate D-Load (N/m/mm)	MAXIMUM HEIGHT OF COVER (Meters) Method A Backfill		
			Method[5] 1	Method[5] 2	Method[5] 3
II	50	75	1.8	4.8	7.9
III	65	100	2.4	6.0	9.7
	80[2]	120[3]	3.0	7.5	11.5
IV	100	150	3.6	8.5	13.7
	120[2]	150[3]	4.2	10.6	17.0
V	140	175	5.1	12.8	20.7
	170[2]	200[3]	6.0	15.0	24.0

NOTES:

(1) Conforms to AASHTO Designation M-170M.

(2) Special strength-cracking D-load.

(3) Interpolated or extrapolated.

(4) Cover heights exceeding tabular values are considered a special design.

(5) Standard Backfill Methods and pipe strength classifications are governed by the tables in Standard Plan A62-D.

- Areas where ground is subject to freezing to considerable depths for lengthy periods.
- Marshy, tidal areas and other areas of subsidence or differential settlement.
- Locations near geologic faults or where potential for liquefaction exists.

(b) Cover between top of pipe and ground surface should be at least 0.75 m, or 0.6 m below the grading plane. In expansive soils, cover should be a minimum of one meter. Some special treatment may be needed in expansive soil, depending on moisture content.

(c) Cast-in-place concrete pipe may be used only if static head is intermittent and less than 3.5 m above center of pipe, and some leakage is acceptable.

(d) Installation under any State Highway Roadbed is only permissible with FHWA and/or headquarters and the Division of Structures approval. Installations outside the roadbed are permissible, but the possibility of future widenings should be considered prior to finalizing the culvert location.

(e) A guide to the type of cement and cement factor to be used with various ranges of sulfate concentrations in the soil and water are shown in Table 854.1B. See Table 854.1A for limitations of use due to soil and water acidity.

(2) *Height of Fill.* The maximum allowable height of cover for cast-in-place concrete pipe is given in Table 854.2. The designer should review Standard Plan A62-D for guidance in using Table 854.2.

Table 854.2

Cast-in-Place Concrete Pipe Fill Height Table

Inside Dia. (mm)	Min. Wall Thickness (mm)	Maximum Fill Height (m)			
		24.0	27.5	31.0	34.5
		(MPa)			
750	75	4.0	4.0	4.3	4.6
900	90	3.7	4.0	4.3	4.6
1050	100	3.4	3.7	4.0	4.3
1200	125	4.0	4.3	4.6	4.9
1350	140	4.0	4.3	4.6	4.9
1500	150	3.7	4.0	4.3	4.6
1650	165	3.7	4.0	4.3	4.6
1800	175	3.4	3.7	4.0	4.3
1950	190	3.4	3.7	4.0	4.3
2100	200	3.4	3.7	4.0	4.3

854.3 Corrugated Steel Pipe and Pipe Arches

(1) *Durability.* The anticipated maintenance free service life of corrugated steel pipe and pipe arch installations is primarily a function of the corrosivity and abrasiveness of the environment into which the pipe is placed. Corrosive potential must be determined from the pH and minimum resistivity tests covered in California Test 643. Abrasive potential must be estimated from bed material that is present and anticipated flow velocities. Refer to Topic 852.1 for a discussion of maintenance free service life.

Consideration should be given to specifying alternative designs when it is possible to achieve the required design service life by either increasing the metal thickness or by using protective coatings.

The following measures are commonly used to prolong the maintenance free service life of metal culverts:

(a) Galvanizing. Under most conditions plain galvanizing of steel pipe is all that is needed; however, the presence of corrosive or abrasive elements may require additional protection.

- Extra Metal Thickness. Added service life can be achieved by adding metal thickness. Since 1.3 mm thick steel culverts is the minimum steel pipe Caltrans allows, it must be limited to locations that are nonabrasive.

- Protective Coatings - The necessity for any coating should be determined considering hydraulic conditions, local experience, possible environmental impacts, and long-term economy. Approved protective coatings are bituminous, which is hot-dipped to cover the entire inside and outside of the pipe; asphalt mastic and polymeric sheet, which can be applied to the inside and/or outside of the pipe; and polymerized asphalt, which is hot-dipped to cover the bottom 90° of the inside and outside of the pipe.

  Citing Section 5650 of the Fish and Game Code, the Department of Fish and Game (DFG) may restrict the use of bituminous coatings on the interior of pipes if they are to be placed in streams which flow continuously or for an extended period (more than 1 to 2 days) after a rainfall event. Their concern is that abraded particles of asphalt could enter the stream and degrade the fish habitat. Where abrasion is unlikely, DFG concerns should be minimal. DFG has indicated that they have no concerns regarding interior application of polymerized asphalt, even under abrasive conditions.

  Where the materials report indicates that soil side corrosion is expected, a bituminous coating or an exterior application of either asphalt mastic or polymeric sheet, as provided in the Standard Specifications, combined with galvanizing of steel, is usually effective in forestalling accelerated corrosion on the backfill side of the pipe. Where soil side corrosion is the only concern, exterior protection may provide up to 25 years of additional service life. For locations where water side corrosion and/or abrasion is of concern, protective coatings, or protective coatings with pavings, in combination with galvanizing will add to the culvert service life to a variable degree, depending upon site conditions and type of coating selected. If hydraulic conditions at the culvert site require a lining on the inside of the pipe or a coating different than that indicated in the Standard Specifications, then the different requirements must be described in the Special Provisions.

Table 854.3A constitutes a guide for estimating the added service life that can be achieved by coatings and invert paving of steel pipes based upon abrasion resistance characteristics. Recently developed coating products, like polymerized asphalt, can provide superior abrasive resistant qualities (as much as 10 or more times that of bituminous coatings of similar thickness). The guide values for years of added service life should be modified where field observations of existing installations show that other values are more accurate. The designer should be aware of the following limitations when using Table 854.3A:

- Channel Materials: If there is no existing culvert, it may be assumed that the channel is potentially abrasive to culvert if sand and/or rocks are present. Presence of silt, clay or heavy vegetation may indicate a non-abrasive flow.

Table 854.3A

Guide for Anticipated Service Life Added to Steel Pipe by Abrasive Resistant Protective Coating

Flow Vel. (m/s)	Channel Materials	Bituminous Coating (yrs.)	Bituminous Coating & Paved Invert (yrs.)	Polymerized Asph. (yrs.)
<1.5	Abrasive	6	15	*
	Non-Abrasive	8	15	*
1.5-2.0	Abrasive	6	12	*
	Non-Abrasive	8	15	*
>2.0	Abrasive	0	5	15
	Non-Abrasive	2	10	25

* Polymerized asphalt invert coating provides adequate abrasion resistance to meet or exceed a 50 year design service life.

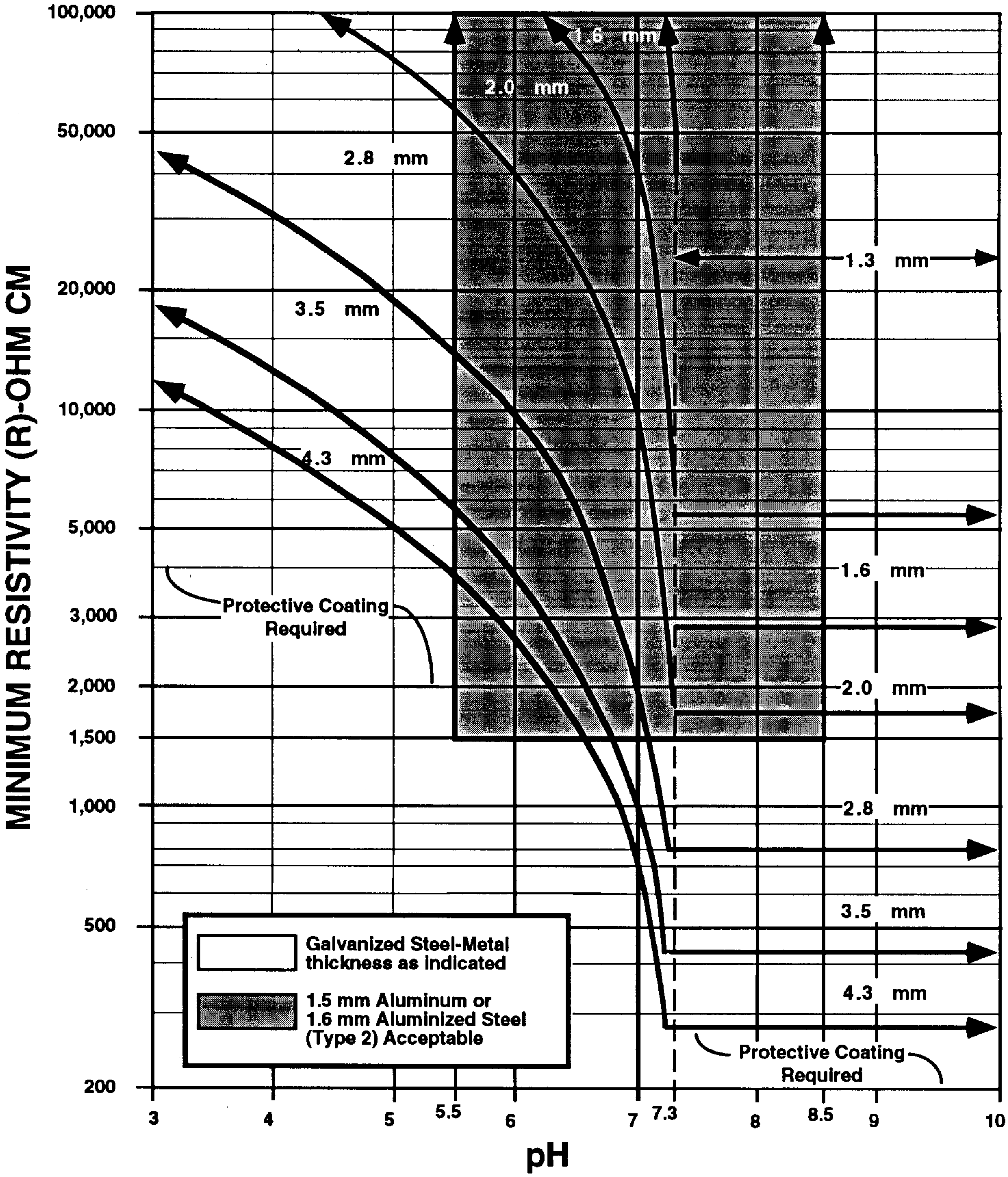
- Flow velocities: For continuous and substantial flow, the years of invert protection can be expected to be one-half of that shown. For the more typical intermittent flow, the velocities indicated in the table should be compared to those generated by the 2-5 year return frequency flood.
- Asphalt mastic (if there are no environ-mental concerns) is an acceptable alternative for bituminous coatings for non-abrasive flow condition on the inside of the culvert. Under these circumstances, a special provision will be required to specify this alternative.

(b) Aluminized Steel (Type 2). Evaluations of aluminized steel (type 2) pipe in place for over 40 years have provided data that substantiate a design service life with respect to corrosion resistance equivalent to aluminum pipe. Therefore, for pH values between 5.5 and 8.5, and minimum resistivity in excess of 1500 ohm-cm, 1.6 mm aluminized steel (type 2) is considered to provide a 50 year design service life. Where abrasion is of concern, aluminized steel (type 2) is considered to be roughly equivalent to galvanized steel. For pH ranges outside the 5.5 and 8.5 limits or minimum resistivity below 1500 ohm-cm, aluminized steel (type 2) should not be used. In no case should the thickness of aluminized steel (type 2) be less than the minimum structural requirements for a given diameter of galvanized steel.

Figure 854.3B should be used to determine the minimum thickness and limitation on the use of corrugated metal pipe for various levels of pH and minimum resistivity. For example, given a soil environment with pH and minimum resistivity levels of 6.5 and 15,000 ohm-cm, respectively, the minimum thicknesses for the various metal pipes are: 1) 2.8 mm galvanized steel, 2) 1.6 mm aluminized steel (type 2) and 3) 1.5 mm aluminum. The minimum thickness of metal pipe obtained from the figure only satisfies corrosion requirements. Overfill require-ments for minimum metal thickness must also be satisfied. The metal thickness of corrugated pipe that satisfies both requirements should be used.

Figure 854.3B

Minimum Thickness of Metal Pipe for 50 Year Maintenance Free Service Life



Notes: 1. For pH and minimum resistivity levels not shown refer to California Test 643.

2. Refer to CULVERT 3 computer program for service life estimate due to various corrosive conditions.

The CULVERT3 (4-16-94) Computer Program, or subsequent upgrades, is also available to help designers estimate service life for various corrosive/ abrasive conditions. This program can be obtained from the District Hydraulics Engineer.

(2) *Strength Requirements*. The strength requirements for corrugated steel pipes and pipe arches, fabricated under acceptable methods contained in the Standard Specifications, are given in Tables 854.3B, C, D, & E.

(a) Design Standards.

- Corrugation Profiles - Corrugated steel pipe and pipe arches are available in 68 mm x 13 mm, 76 mm x 25 mm, and 125 mm x 25 mm profiles with helical corrugations, and 68 mm x 13 mm profiles with annular corrugations.
- Metal Thickness - Corrugated steel pipe and pipe arches are available in the thickness as indicated on Tables 854.3B, C, D & E. Where a maximum overfill is not listed on these tables, the pipe or arch size is not normally available in that thickness.
- Height of Fill - The allowable overfill heights for corrugated steel pipe and pipe arches for the various diameters or arch sizes and metal thickness are shown on Tables 854.3B, C, D & E.

(b) Basic Premise. To properly use the above mentioned tables, the designer should be aware of the premises on which the tables are based as well as their limitations. The design tables presuppose:

- That bedding and backfill satisfy the terms of the Standard Specifications, the conditions of cover, and pipe size required by the plans and the essentials of Index 829.2.
- That a small amount of settlement will occur under the culvert, equal in magnitude to that of the adjoining material outside the trench.

(c) Limitations. In using the tables, the following restrictions must be kept in mind.

- The values given for each size of pipe constitute the maximum height of overfill or cover over the pipe for the thickness of metal and kind of corrugation.
- The thickness shown is the structural minimum. Where abrasive conditions are anticipated, additional metal thickness or a paved invert as stated under Index 854.3(4) should be provided when required to fulfill the design service life requirements of Topic 852.
- Where needed, adequate provisions for corrosion resistance must be made to achieve the required design service life called for in the references mentioned herein.
- Table 854.3E shows the limit of heights of cover for corrugated steel pipe arches based on the supporting soil sustaining a bearing pressure varying between 240 and 405 kN/m^2. Table 854.4C shows similar values for corrugated aluminum pipe arches.

(d) Special Designs. If the height of overfill exceeds the tabular values, or if the foundation investigation reveals that the supporting soil will not develop the bearing pressure on which the overfill heights for pipe arches are based, a special design prepared by the Division of Structures is required.

(3) *Shapes*. Corrugated steel pipe and pipe arches are available in the diameters and arch shapes as indicated on the maximum height of cover tables. For larger diameters, arch spans or special shapes, see Index 854.6.

(4) *Invert Protection*. Invert protection should be considered for corrugated steel culverts exposed to excessive wear from abrasive flows. Severe abrasion usually occurs when the flow velocity exceeds 4.5 m/s and contains a bedload. When severe abrasion is anticipated, special designs should be

investigated and considered. Typical invert protection includes invert paving with asphalt concrete or portland cement concrete with wire mesh reinforcement, and invert lining with metal plate, channel iron, or rails. Invert linings should cover the lower fourth of the periphery of circular pipes, and the lower third of pipe arches. Additional metal thickness will increase service life. Reducing the velocity within the culvert is an effective method of preventing severe abrasion.

854.4 Corrugated Aluminum Pipe and Pipe Arches

(1) *Durability.* Aluminum culverts may be specified as an alternate culvert material. When a 50-year maintenance free service life of aluminum pipe is required the pH and minimum resistivity, as determined by California Test Method 643, must be known and the following conditions met:

(a) The pH of the soil, backfill, and effluent is within the range of 5.5 and 8.5, inclusive. Bituminous coatings are not recommended.

(b) The minimum resistivity of the soil, backfill, and effluent is 1500 ohm-centimeters or greater.

(c) Under similar conditions, aluminum culverts will abrade approximately three times faster than steel culverts. Therefore, aluminum culverts are not recommended where abrasive materials are present, and where flow velocities would encourage abrasion to occur. Culvert flow velocities that frequently exceed 1.5 m/s should be carefully evaluated prior to selecting aluminum as an allowable alternate.

(d) Aluminum culverts should not be installed in an environment where other aluminum culverts have exhibited significant distress, such as extensive perforation or loss of invert, for whatever reason, apparent or not.

(e) Aluminum may be considered for side drains in environments having the following parameters:

- When pH is between 5.5 and 8.5 and the minimum resistivity is between 500 and 1500 ohm-cm.
- When pH is between 5.0 and 5.5 or between 8.5 and 9.0 and the minimum resistivity is greater than 1500 ohm-cm.

For these conditions, the METS should be contacted to confirm the advisability of using aluminum on specific projects.

(f) Aluminum must not be used as a section or extension of a culvert containing steel sections.

Figure 854.3B should be used to determine the limitations on the use of corrugated aluminum pipe for various levels of pH and minimum resistivity. The minimum thickness (1.5 mm) of aluminum pipe obtained from the chart only satisfies corrosion requirements. Overfill requirements for minimum metal thickness must also be satisfied. The metal thickness of corrugated aluminum pipe should satisfy both requirements.

(2) *Strength Requirements.* The strength requirements for corrugated aluminum pipe and pipe arches fabricated under the acceptable methods contained in the Standard Specifications, are given in Tables 854.4A, B & C.

(a) Design Standards.

- Corrugation Profiles - Corrugated aluminum pipe and pipe arches are available in 68 mm x 13 mm and 75 mm x 25 mm profiles with helical or annular corrugations.
- Metal thickness - Corrugated aluminum pipe and pipe arches are available in the thickness as indicated on Tables 854.4A, B & C. Where a maximum overfill is not listed on these tables, the pipe or pipe arch is not normally available in that thickness.

- Height of Fill - The allowable overfill heights for corrugated aluminum pipe and pipe arches for various diameters and metal thickness are shown on Tables 854.4A, B & C.

To properly use the above mentioned tables, the designer should be aware of the basic premises on which the tables are based as well as their limitations. (See Index 854.3(2)).

(3) *Shapes*. Corrugated aluminum pipe and pipe arches are available in the diameters and arch shapes as indicated on the maximum height of cover tables. Helical corrugated pipe must be specified if anticipated heights of cover exceed the tabulated values for annular corrugated pipe.

For larger diameters, arch spans or special shapes, see Index 854.6.

(4) *Invert Protection.* Invert protection of corrugated aluminum is not recommended.

854.5 Special Purpose Types

(1) *Spiral Rib Steel.* Galvanized steel spiral rib pipe is fabricated using sheet steel and lock seam fabrication as used for helical corrugated metal pipe. The thickness of metal and zinc coating is identical to that for corrugated pipe. Spiral rib pipe has a lower roughness coefficient (Manning's "n") than corrugated metal pipe.

The rib profile does not provided as much earth bearing strength as the standard corrugation profiles. Tables 854.5A & B give the maximum height of overfill for steel spiral rib pipe constructed under the acceptable methods contained in the Standard Specifications and essentials discussed in Index 829.2.

(2) *Smooth Steel.* Smooth steel (welded) pipe can be utilized for drainage facilities under conditions where corrugated metal or concrete pipe will not meet the structural or design service life requirements.

(3) *Spiral Rib Aluminum.* Aluminum spiral rib pipe is similar to spiral rib steel. Table 854.5C gives the maximum overfill for aluminum spiral rib pipe constructed under the acceptable methods contained in the Standard Specifications and the essentials discussed in Index 829.2.

(4) *Proprietary Pipe.* See Index 602.1(6) for further discussion and guidelines on the use of proprietary items.

854.6 Structural Metal Plate

(1) *Pipe and Arches.* Structural plate pipes and arches are available in steel and aluminum for the diameters and thickness as shown on Tables 854.6A, B, C & D.

(2) *Strength Requirements.*

(a) Design Standards.

- Corrugation Profiles - Structural plate pipe and arches are available in a 152 mm x 51 mm corrugation for steel and a 230 mm x 64 mm corrugation profile for aluminum.

- Metal Thickness - structural plate pipe and pipe arches are available in thickness as indicated on Tables 854.6A, B, C & D.

- Height of Fill - The allowable height of cover over structural plate pipe and pipe arches for the available diameters and thickness are shown on Tables 854.6A, B, C & D.

Where a maximum overfill is not listed on these tables, the pipe or arch size is not normally available in that thickness.

(b) Basic Premise. To properly use the above mentioned tables, the designer should be aware of the premises on which the tables are based as well as their limitations. The design tables presuppose:

- That bedding and backfill satisfy the terms of the Standard Specifications, the conditions of cover, and pipe or arch size required by the plans and the essentials of Index 829.2.

- That a small amount of settlement will occur under the culvert, equal in magnitude to that of the adjoining material outside the trench.

Table 854.3B

Corrugated Steel Pipe
Helical Corrugations

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m) Metal Thickness (mm)					
	1.32	1.63	2.01	2.77	3.51	4.27
	68 mm x 13 mm Corrugations					
300-375	30.0	30.0	--	--	--	--
450	27.0	30.0	--	--	--	--
525	23.5	29.5	30.0	--	--	--
600	20.5	25.5	30.0	--	--	--
750	16.0	20.5	25.5	30.0	--	--
900	13.5	17.0	21.5	30.0	30.0	--
1050	11.5	14.5	18.5	25.5	30.0	--
1200	--	13.0	16.0	22.5	28.5	30.0
1350	--	--	14.0	20.0	25.5	30.0
1500	--	--	--	18.0	23.0	28.0
1650	--	--	--	--	21.0	25.5
1800	--	--	--	--	19.0	23.5
1950	--	--	--	--	--	20.5
2100	--	--	--	--	--	18.0
	75 mm x 25 mm Corrugations					
1200	--	14.5	18.5	25.5	33.0	40.5
1350	--	13.0	16.0	23.0	29.5	36.0
1500	--	11.5	14.5	20.5	26.5	32.0
1650	--	10.5	13.5	18.5	24.0	29.5
1800	--	10.0	12.0	17.0	22.0	27.0
1950	--	9.0	11.5	16.0	20.5	25.0
2100	--	8.5	10.5	14.5	19.0	23.0
2250	--	7.5	10.0	13.5	17.5	21.5
2400	--	--	9.0	13.0	16.5	20.0
2550	--	--	8.5	12.0	15.5	19.0
2700	--	--	--	11.5	14.5	18.0
2850	--	--	--	10.5	14.0	17.0
3000	--	--	--	10.0	13.0	16.0

NOTE:

(1) When flow velocity exceeds 1.5 $^{m}/_{s}$ under abrasive conditions, thicker metal may be required.

Table 854.3C

Corrugated Steel Pipe
Helical Corrugations

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)			
	Metal Thickness (mm)			
	1.63	2.010	2.77	3.51
	125 mm x 25 mm Corrugations			
1200	13.0	16.0	23.0	--
1350	11.5	14.0	20.5	26.0
1500	10.5	13.5	18.5	23.5
1650	9.5	12.5	17.0	21.5
1800	8.5	11.5	15.0	19.5
1950	8.0	10.0	14.0	18.0
2100	7.5	9.0	13.0	17.0
2250	7.0	8.5	12.0	15.5
2400	--	8.0	11.5	14.5
2550	--	7.5	10.5	13.5
2700	--	--	10.0	13.0
2850	--	--	9.5	12.0
3000	--	--	9.0	11.5

NOTE:
(1) When flow velocity exceeds 1.5 m/s under abrasive conditions, thicker metal may be required.

Table 854.3D

Corrugated Steel Pipe
68 mm x 13 mm Annular Corrugations

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)				
	Metal Thickness (mm)				
	1.63	2.01	2.77	3.51	4.27
450	16.5	--	--	--	--
525	14.5	--	--	--	--
600	12.5	13.5	--	--	--
750	10.0	10.5	--	--	--
900	8.0	9.0	11.5	--	--
1050	9.0	12.5	19.0	20.5	--
1200	8.0	11.0	16.5	18.5	19.0
1350	--	10.0	14.5	16.0	17.0
1500	--	--	13.0	14.5	15.0
1650	--	--	--	13.0	13.5
1800	--	--	--	12.0	13.0
1950	--	--	--	--	11.5
2100	--	--	--	--	11.0

NOTE:

(1) When flow velocity exceeds 1.5 m/s under abrasive conditions, thicker metal may be required.

Table 854.3E

Corrugated Steel Pipe Arches
Helical or Annular Corrugations

Span-Rise (mm)	Design Bearing (kN/m2)	Minimum Corner Radius (mm)	MAXIMUM HEIGHT OF COVER (m) Metal Thickness (mm) 2.01	2.77	3.51	4.27
530 x 380	240	75	3.0	--	--	--
610 x 460	265	75	3.0	--	--	--
710 x 510	310	75	3.0	--	--	--
885 x 610	405	75	3.0	--	--	--
1060 x 740	405	90	3.0	--	--	--
1240 x 840	405	100	3.0	--	--	--
1440 x 970	385	125	--	3.0	--	--
1620 x 1100	360	150	--	3.0	--	--
1800 x 1200	335	175	--	--	3.0	--
1950 x 1320	335	200	--	--	--	3.0
2100 x 1450	310	225	--	--	--	3.0

NOTES:
(1) When flow velocity exceeds 1.5 m/s under abrasive conditions, thicker metal may be required.
(2) Cover limited by corner soil bearing pressure as shown.

Table 854.4A

Corrugated Aluminum Pipe
Annular Corrugations

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m) Metal Thickness (mm)				
	1.52	1.91	2.67	3.43	4.17
	68 mm x 13 mm Corrugations				
300	13.5	13.5	--	--	--
375	10.5	10.5	18.5	--	--
450	9.0	9.0	15.5	--	--
525	7.5	7.5	13.0	--	--
600	6.5	6.5	11.5	12.0	--
750	--	5.0	9.0	9.5	--
900	--	4.5	7.5	8.0	--
1050	--	--	13.5	14.0	--
1200	--	--	11.5	12.0	12.5
1350	--	--	--	11.0	11.5
1500	--	--	--	10.0	10.0
1650	--	--	--	--	9.0
1800	--	--	--	--	8.0
	75 mm x 25 mm Corrugations				
750	10.0	12.0	17.0	25.0	--
900	8.0	10.0	13.5	20.5	27.0
1050	7.0	8.5	12.0	18.0	23.0
1200	6.0	7.5	10.5	15.5	20.0
1350	5.5	6.5	9.0	13.5	18.0
1500	5.0	6.0	8.0	12.5	16.0
1650	4.5	5.5	7.5	11.5	14.5
1800	4.0	5.0	6.5	10.5	13.5
1950	--	4.5	6.5	9.5	12.5
2100	--	--	6.0	9.0	11.5
2250	--	--	5.5	8.0	10.5
2400	--	--	5.0	7.5	10.0
2550	--	--	--	7.5	9.5
2700	--	--	--	6.5	9.0
2850	--	--	--	--	8.0
3000	--	--	--	--	7.0

NOTE:
(1) Not recommended under abrasive conditions.

Table 854.4B

Corrugated Aluminum Pipe
Helical Corrugations

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)				
	Metal Thickness (mm)				
	1.52	1.91	2.67	3.43	4.17
	68 mm x 13 mm Corrugations				
300	30.0	30.0	--	--	--
375	30.0	30.0	30.0	--	--
450	24.5	30.0	30.0	--	--
525	21.5	26.5	30.0	--	--
600	18.5	23.0	30.0	30.0	--
750	--	18.5	26.0	30.0	--
900	--	15.5	21.5	28.0	--
1050	--	--	18.5	24.0	--
1200	--	--	16.0	20.5	25.5
1350	--	--	--	17.0	21.0
1500	--	--	--	13.5	17.0
1650	--	--	--	--	13.5
1800	--	--	--	--	11.0
	75 mm x 25 mm Corrugations				
750	17.0	21.5	30.0	30.0	--
900	14.0	18.0	25.0	30.0	30.0
1050	12.0	15.0	21.5	28.5	30.0
1200	10.5	13.5	18.5	25.0	29.5
1350	9.5	12.0	16.5	22.5	26.0
1500	8.5	10.5	15.0	20.0	23.5
1650	7.5	10.0	13.5	18.5	21.5
1800	7.0	9.0	12.5	17.0	19.5
1950	--	8.0	11.5	15.0	18.0
2100	--	--	10.5	14.5	17.0
2250	--	--	10.0	13.5	15.5
2400	--	--	9.0	12.0	14.5
2550	--	--	--	11.0	13.0
2700	--	--	--	10.0	12.0
2850	--	--	--	--	10.5
3000	--	--	--	--	9.5

NOTE:
(1) Not recommended under abrasive conditions.

Table 854.4C

Corrugated Aluminum Pipe Arches
Helical or Annular Corrugations

Span-Rise (mm)	Req'd Bearing (kN/m2)	Minimum Corner Radius (mm)	MAXIMUM HEIGHT OF COVER (m) Metal Thickness (mm)				
			1.52	1.91	2.67	3.43	4.17
430 x 330	190	75	3.0	--	--	--	--
530 x 380	240	75	3.0	--	--	--	--
610 x 460	265	75	3.0	--	--	--	--
710 x 510	310	75	3.0	--	--	--	--
885 x 610	385	75		3.0	--	--	--
1060 x 740	405	90	--	3.0	--	--	--
1240 x 840	405	100	--	--	3.0	--	--
1440 x 970	385	125	--	--	--	3.0	--
1620 x 1100	360	150	--	--	--	3.0	--
1800 x 1200	335	175	--	--	--	--	3.0

NOTES:
(1) Cover is limited by corner soil bearing pressure as shown.
(2) Not recommended under abrasive conditions.

Table 854.5A

Steel Spiral Rib Pipe
19 mm x 25 mm Ribs at 292 mm Pitch

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)		
	Metal Thickness (mm)		
	1.63	2.01	2.77
600	13.5	17.0	24.0
750	11.0	13.5	19.0
900	9.0	11.5	16.0
1050	8.0	10.0	13.5
1200	6.5	8.5	12.0
1350	6.0	7.5	10.5
1500	5.5	6.5	9.5
1650	--	6.0	8.5
1800	--	5.5	8.0

NOTES:

(1) When flow velocity exceeds 1.5 m/s under abrasive conditions, thicker metal may be required.

(2) Plans for proposed use of pipe diameters greater than 1800 mm must be submitted to the Office of State Highway Drainage Design for review and approval.

Table 854.5B

Steel Spiral Rib Pipe
19 mm x 19 mm Ribs at 190 mm Pitch

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)		
	Metal Thickness (mm)		
	1.63	2.01	2.77
600	13.5	17.5	24.0
750	11.0	13.5	19.0
900	9.0	11.5	16.0
1050	8.0	10.0	13.5
1200	6.5	8.5	12.0
1350	6.0	7.5	10.5
1500	--	6.5	9.5
1650	--	--	8.5
1800	--	--	8.0

NOTES:

(1) When flow velocity exceeds 1.5 m/s under abrasive conditions, thicker metal may be required.

(2) Plans for proposed use of pipe diameters greater than 1800 mm must be submitted to the Office of State Highway Drainage Design for review and approval.

Table 854.5C

Aluminum Spiral Rib Pipe
19 mm x 19 mm Ribs at 190 mm Pitch

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)		
	Metal Thickness (mm)		
	1.52	1.91	2.67
600	10.5	13.0	18.5
750	8.0	10.5	14.5
900	7.0	8.5	12.0
1050	6.0	7.5	10.5
1200	5.0	6.5	9.0
1350	--	6.0	8.0
1500	--	--	7.5
1650	--	--	--
1800	--	--	--

NOTES:

(1) Not recommended under abrasive conditions.

(2) Plans for proposed use of pipe diameters greater than 1800 mm must be sumbitted to the Office of State Highway Drainage Design for review and approval.

Table 854.6A

Structural Steel Plate Pipe
152 mm x 51 mm Corrugations

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)					
	Metal Thickness (mm)					
	2.82	3.56	4.32	5.54	6.32	7.11
1500	17.0	24.5	32.0	42.0	48.5	54.5
1655	15.0	22.5	29.5	38.5	44.0	49.0
1810	14.0	20.5	27.0	35.0	40.0	45.5
1965	13.0	19.0	24.5	32.5	37.0	41.5
2120	12.0	17.5	23.0	30.0	34.5	39.0
2275	11.0	16.5	21.5	28.0	32.0	36.0
2430	10.5	15.5	20.0	26.5	30.0	34.0
2585	10.0	14.5	19.0	25.0	28.5	32.0
2740	9.0	13.5	18.0	23.5	27.0	30.0
2895	9.0	13.0	17.0	22.5	25.5	28.5
3050	8.0	12.0	16.0	21.0	24.0	27.0
3205	8.0	11.5	15.0	20.0	23.0	26.0
3360	7.5	11.5	14.5	19.0	22.0	24.5
3515	7.5	10.5	14.0	18.5	21.0	23.5
3670	7.0	10.5	13.5	17.5	20.0	22.5
3825	6.5	10.0	13.0	17.0	19.0	21.5
3980	6.5	9.5	12.0	16.0	18.5	20.5
4135	6.0	9.0	12.0	15.5	17.5	20.0
4290	6.0	9.0	11.5	15.0	17.0	19.5
4445	6.0	8.5	11.0	14.5	16.5	18.5
4600	5.5	8.0	10.5	14.0	16.0	18.0
4755	5.0	8.0	10.5	13.5	15.5	17.5
4910	--	7.5	10.0	13.0	15.0	17.0
5065	--	7.5	10.0	13.0	14.5	16.5
5220	--	7.5	9.5	12.0	14.0	16.0
5375	--	7.0	9.0	12.0	13.5	15.5
5530	--	--	9.0	11.5	13.5	15.0
5685	--	--	8.5	11.5	13.0	14.5
5840	--	--	8.5	11.0	12.5	14.5
5995	--	--	8.0	10.5	12.0	13.5
6150	--	--	--	10.5	12.0	13.5
6305	--	--	--	10.0	11.5	13.0
6460	--	--	--	10.0	11.5	13.0

NOTE:
(1) When flow velocities exceeds 1.5 $^{m}/_{s}$ under abrasive conditions thicker metal may be required.

Table 854.6B

Structural Steel Plate Pipe Arches
152 mm x 51 mm Corrugations

MAXIMUM HEIGHT OF COVER (m)			
		Corner Soil Bearing - 285 $^{kN}/_{m^2}$	
Span	Rise	Metal Thickness (mm)	
(mm)	(mm)	2.82	3.56
		457 mm Corner Radius	
1850	1400	6.5	--
2130	1550	5.5	--
2410	1700	5.0	--
2690	1850	4.5	--
2970	2010	4.0	--
3330	2160	3.5	--
		787 mm Corner Radius	
4040	2840	5.0	--
4320	3000	4.5	--
4670	3150	4.5	--
4950	3300	4.0	--
5230	3450	3.5	--
5510	3610	3.5	--
5870	3760	3.5	--
6070	3910	--	3.0
6270	4010	--	3.0

NOTES:
(1) For intermediate sizes, the depth of cover may be interpolated.
(2) The 787 mm corner radius arch should be specified when conditions will permit it use.

Table 854.6C

Structural Aluminum Plate Pipe
230 mm x 64 mm Corrugations

Diameter (mm)	MAXIMUM HEIGHT OF COVER (m)						
	Metal Thickness (mm)						
	2.54	3.18	3.81	4.44	5.08	5.72	6.35
1500	11.0	16.5	20.0	23.5	27.0	30.0	30.0
1655	10.0	15.0	18.5	21.5	24.5	27.5	30.0
1810	9.0	13.5	17.0	19.5	22.5	25.5	28.0
1965	8.5	12.5	15.5	18.0	20.5	23.0	26.0
2120	8.0	11.5	14.5	17.0	19.0	21.5	24.0
2275	7.5	11.0	13.5	15.5	18.0	20.0	22.5
2430	7.0	10.0	12.5	14.5	17.0	19.0	21.0
2585	6.5	9.5	12.0	13.5	16.0	17.5	20.0
2740	6.0	9.0	11.5	13.0	15.0	17.0	18.5
2895	6.0	8.5	10.5	12.0	14.0	16.0	17.5
3050	5.5	8.0	10.0	11.5	13.5	15.0	17.0
3205	5.0	7.5	9.5	11.0	13.0	14.5	16.0
3360	5.0	7.5	9.0	10.5	12.0	13.5	15.0
3515	5.0	7.0	8.5	10.0	11.5	13.0	14.5
3670	4.5	6.5	8.0	10.0	11.0	12.5	14.0
3825	--	6.5	8.0	9.5	10.5	12.0	13.5
3980	--	6.0	7.5	9.0	10.5	11.5	13.0
4135	--	--	7.5	8.5	10.0	11.0	12.5
4290	--	--	7.0	8.0	9.5	10.5	12.0
4445	--	--	6.5	8.0	9.0	10.5	11.5
4600	--	--	--	7.5	9.0	10.0	11.5
4755	--	--	--	7.5	8.5	10.0	10.5
4910	--	--	--	--	8.0	9.5	10.5
5065	--	--	--	--	8.0	9.0	10.0
5220	--	--	--	--	8.0	9.0	10.0
5375	--	--	--	--	--	8.5	9.5
5530	--	--	--	--	--	8.0	9.0
5685	--	--	--	--	--	--	9.0
5840	--	--	--	--	--	--	9.0

NOTE:
(1) Not recommended under abrasive conditions.

Table 854.6D

Structural Aluminum Plate Pipe Arches
230 mm x 64 mm Corrugations

		MAXIMUM HEIGHT OF COVER (m)					
		Corner Soil Bearing - 285 kN/m^2					
		Metal Thickness (mm)					
Span	Rise	2.54	3.18	3.81	4.44	5.08	5.72
2010	1730	8.5	--	--	--	--	--
2360	1830	7.0	--	--	--	--	--
2690	1930	6.0	--	--	--	--	--
3020	2030	5.5	--	--	--	--	--
3120	2060	5.5	6.5	--	--	--	--
3380	2130	5.0	6.0	6.0	--	--	--
3730	2210	4.5	5.5	5.5	--	--	--
3940	2290	4.5	5.0	5.0	--	--	--
3990	2490	4.5	5.0	5.0	--	--	--
4240	2570	3.5	5.0	5.0	--	--	--
4270	2620	3.5	4.5	5.0	--	--	--
4470	2950	--	4.5	4.5	--	--	--
4750	3100	--	4.5	4.5	--	--	--
4900	3150	--	4.0	4.0	--	--	--
5110	3250	--	--	4.0	--	--	--
5410	3400	--	--	--	3.5	--	--
5690	3560	--	--	--	3.5	--	--
6050	3680	--	--	--	--	3.0	--
6350	3840	--	--	--	--	--	3.0
6550	3940	--	--	--	--	--	3.0

NOTE:
(1) Not recommended under abrasive conditions.
(2) 787 mm Corner Raduis

(c) Limitations. In using the tables, the following restrictions should be kept in mind.

- The values given for each size of structural plate pipe or arch constitute the maximum height of overfill or cover over the pipe or arch for the thickness of metal and kind of corrugation.

- The thickness shown is the structural minimum. For steel pipe or pipe arches, where abrasive conditions are anticipated, additional metal thickness or a paved invert should be provided when required to fulfill the design service life requirements.

- Where needed, adequate provisions for corrosion resistance must be made to achieve the required design service life called for in the references mentioned herein.

- Tables 854.6B & D show the limit of heights of cover for structural plate arches based on the supporting soil sustaining a bearing pressure of 285 kN/m^2 at the corners.

(d) Special Designs. If the height of overfill exceeds the tabular values, or if the foundation investigation reveals that the supporting soil will not develop the bearing pressure on which the overfill heights for structural plate pipe or pipe arches are based, a special design prepared by the Division of Structures is required.

(3) Arches. Design details with maximum allowable overfills for structural plate arches, with cast in place concrete footings may be obtained from the Division of Structures.

(4) Vehicular Underpasses. Design details with maximum allowable overfills for structural plate vehicular underpasses with spans from 3708 mm to 6198 mm, inclusive, are given in the Standard Plans. These designs are based on bearing soil pressures from 135 to 555 kN/m^2.

(5) Special Shapes.

(a) Long Span. (Text Later)

- Arch
- Low Profile Arch
- High Profile Arch

(b) Ellipse. (Text Later)

- Vertical
- Horizontal

(c) Inverted Box. (Text Later)

(d) Box. (Text Later)

(6) Tunnel Liner Plate.

The Division of Structures will prepare designs upon request.

854.7 Concrete Box and Arch Culverts

(1) Box Culverts. Single and multiple span reinforced concrete box culverts are completely detailed in the Standard Plans. Strength classifications are shown for 3 m and 6 m overfills.

Standard Detail Sheets are available for precast reinforced concrete box culverts. They may be obtained electronically via microstation, from the District Hydraulics Engineer or by contacting the Division of Structures. Precast reinforced concrete box culverts require a minimum of 0.3 m of overfill and are not to exceed 3.6 m in span length. Special details are necessary if precast boxes are proposed as extensions for existing box culverts. Where the use of precast box culverts is applicable, the project plans should include them as an alternative to cast-in-place construction. Because the standard measurement and payment clauses for precast RCB's differ from cast-in-place construction, precast units must be identified as an alternative on the standard detail sheets and the special provision must be appropriately modified.

(2) Concrete Arch Culverts. Design details for concrete arch culverts in 0.3 m span increments from 1.8 m to 6.7 m, inclusive, allowing a maximum overfill height up to 18 m, are given in the Standard Plans. These designs are based on footing soil pressures ranging from 230 to 720 kN/m^2.

854.8 Plastic Pipe

(1) *Durability*. Plastic pipe culverts exhibit good abrasion resistance and are virtually corrosion free, permitting a 50 year maintenance free service life under most conditions. Long term exposure to direct sunlight can lead to brittleness in polyvinyl chloride (PVC) pipes, and such situations should be avoided.

In areas with high fire potential, use limitations or modifications of plastic pipe should be considered. Application limitations may include down drains and projecting ends of cross drains in densely vegetated or grassy locations. The projecting ends of plastic pipe cross drains can be replaced with corrugated metal pipe, concrete pipe, concrete headwalls or wingwalls, or other modifications, thereby reducing the potential of fire damage. The connection between the plastic pipe and the modified end piece would be nonstandard.

(2) *Strength Requirements.*

(a) Design Standards

- Materials - Plastic pipe shall be either Type C (corrugated exterior and interior) corrugated polyethylene pipe, Type S (corrugated exterior and smooth interior) corrugated polyethylene pipe, profile wall polyethylene pipe, profile wall polyvinyl chloride pipe, or ribbed polyvinyl chloride pipe.

- Height of Fill - The allowable overfill heights for plastic pipe for various diameters are shown in Table 854.8.

(b) Basic Premise. To properly use the plastic pipe height of fill table, the designer should be aware of the basic premises on which the table are based as well as their limitations. The design table presupposes:

- That bedding and backfill satisfy the terms of the Standard Specifications, the conditions of cover, and pipe size required by the plans and the essentials of Index 829.2.

- That a small amount of settlement will occur under the culvert, equal in magnitude to that of the adjoining material outside the trench.

Table 854.8
Thermoplastic Pipe Fill Height Tables

High Density Polyethylene (HDPE) Corrugated Pipe

Size (mm)	Maximum Height of Cover (m)
300	9.0
375	9.0
450	9.0
600	9.0
750	9.0
900	9.0
1050	6.0
1200	6.0

High Density Polyethylene (HDPE) Ribbed Pipe

Size (mm)	Maximum Height of Cover (m)
450	7.3
525	7.3
600	7.3

Polyvinyl Chloride (PVC) Ribbed Pipe

Size (mm)	Maximum Height of Cover (m)
450	8.2
525	7.9
600	7.6
675	7.3
750	7.0
900	6.7
1050	6.4
1200	6.1

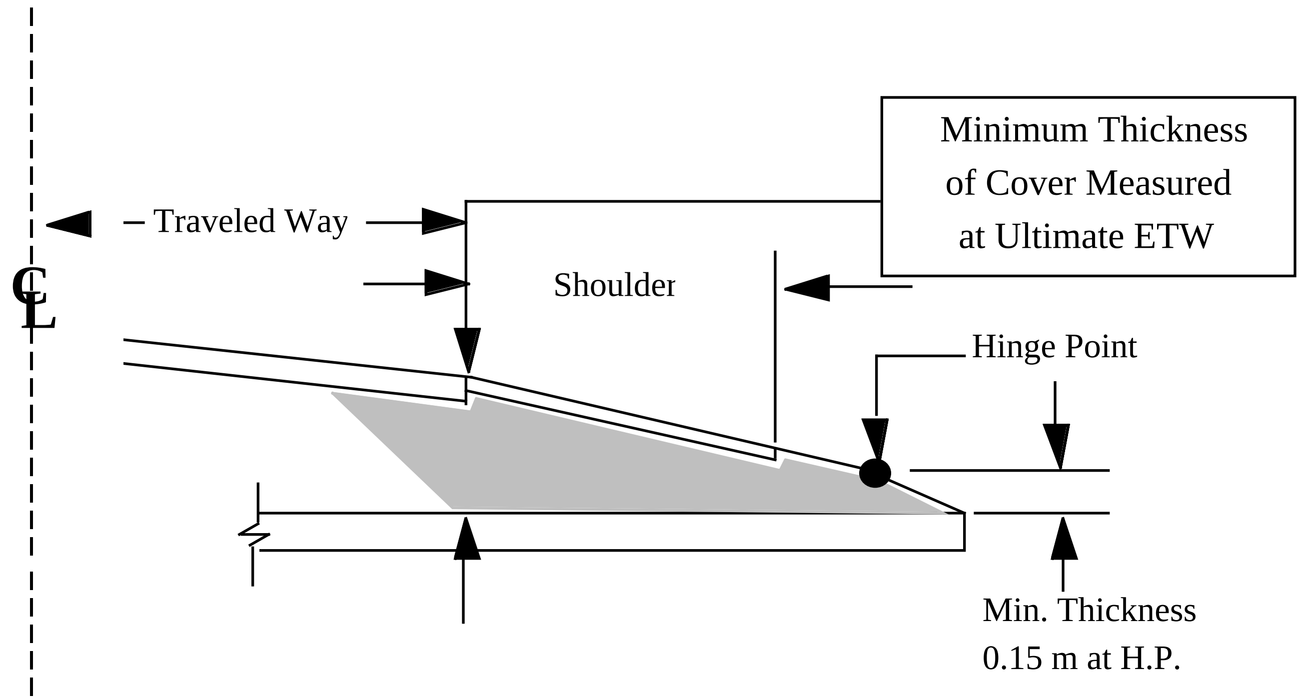
854.9 Minimum Height of Cover

Table 854.9 gives the minimum thickness of cover required for design purposes over pipes and pipe arches. For construction purposes, a minimum cover of 150 mm greater than the roadway structural section is desirable for all types of pipe.

Class 4 concrete backfill may be used for culverts when it is necessary to have less than 0.6 m of cover below the top of a flexible pavement, except that minor concrete backfill must not be placed against aluminum or aluminized culverts. A minimum of 150 mm of concrete backfill should be used at the sides of a culvert.

Table 854.9

Minimum Thickness of Cover for Culverts



MINIMUM THICKNESS OF COVER AT ETW

SURFACE TYPE	Corrugated metal pipes and pipe-arches	Structural plate pipes and pipe-arches	Reinforced concrete pipes	Plastic pipes	Cast-In-Place concrete pipes
Flexible Pavements or Unpaved	1/5 (dia. or span) or 0.6 m minimum.	1/8 (dia. or span) or 0.6 m minimum	0.6 m minimum	0.6 m minimum	Structural Section plus 0.6 m.
Rigid Pavements	1/5 (dia. or span) or 0.4 m minimum.	1/8 (dia. or span) or 0.4 m minimum	0.3 m minimum	0.6 m minimum	Structural Section plus 0.6 m.

Note: See Index 854.2(1)(d) for necessary approvals prior to placing cast-in-place concrete pipes under the roadway.